

(12) **UK Patent Application** (19) **GB** (11) **2 235 444** (13) **A**  
(43) Date of A publication 06.03.1991

(21) Application No 9008943.4

(22) Date of filing 20.04.1990

(30) Priority data

(31) 601333

(32) 31.05.1989

(33) CA

(71) Applicant

Mitel Corporation

(Incorporated in Canada - Ontario)

P O Box 13089, Kanata, Ontario, K2K 1X3, Canada

(72) Inventor

Luc M. Ouellet

(74) Agent and/or Address for Service

John Orchard & Co

Staple Inn Buildings North, High Holborn, London,  
WC1V 7PZ, United Kingdom

(51) INT CL<sup>5</sup>

H01L 23/28, B32B 17/06, H01L 21/314

(52) UK CL (Edition K)

C1M MVN M468

H1K KJAC K1EA K1EB K3T1C K3U6A K5B1 K5B2

K5B5 K5C3L K5H2L K5L K8PC

U1S S1421 S1422 S2285 S3010

(56) Documents cited

EP 0327412 A

Butherus et al (1985) J.Vac. Sci.Technol.B3(5)  
pp.1352-1356

(58) Field of search

UK CL (Edition K) C1M MVH MVJ MVN, H1K KJAC  
KJAX

INT CL<sup>5</sup> B32B, H01L

Online: DIALOG; WPI

(54) **A method of producing insulating layers**

(57) Comprises spinning a film of spin-on-glass (SOG) over a semiconductor substrate, precuring the film of SOG at an elevated temperature sufficient to remove the bulk of solvent and curing the film of SOG in a plasma in a plasma reactor of a type exhibiting a self-biased RF discharge adjacent to the SOG for a period of time sufficient to exclude the bulk of SiOH, organic volatiles and H<sub>2</sub>O from the layer.

01                   This invention relates to a method of producing layers on  
02                   a substrate and to a product thereof. Passivating or dielectric  
03                   layers formed of spin-on-glass that are useful in semiconductor  
04                   integrated circuits, liquid crystal, electrochromic or electro-  
05                   luminescent displays, as anti-reflective coatings, and corrosion or  
06                   chemical protective coatings, are examples of layers that may be  
07                   produced by a method in accordance with the invention. The inven-  
08                   tion also relates, among other things, to products incorporating  
09                   one or more of such layers.

10                   Spin-on glasses (SOG) have been described  
11                   as being able to be used for the purpose of  
12                   planarizing integrated circuits. Because of their  
13                   inherent filling and planarizing properties, their use  
14                   is particularly attractive as the size of  
15                   semiconductor integrated circuits decreases, and when  
16                   multiple level metallization is needed.

17                   Unfortunately, cured SOG has been found to  
18                   be unstable in moist air and water, tending to absorb  
19                   water and form silanol groups, SiOH.

20                   SOG and its method of curing have been  
21                   described in the article by A. Schiltz entitled  
22                   ADVANTAGES OF USING SPIN-ON-GLASS LAYER IN  
23                   INTERCONNECTION DIELECTRIC PLANARIZATION, published in  
24                   "Microelectronic Engineering" 5 (1986) pp. 413-421 by  
25                   Elsevier Science Publishers BV (North Holland), and  
26                   the article O<sub>2</sub> PLASMA-CONVERTED SPIN-ON-GLASS FOR  
27                   PLANARIZATION by A.D. Butherus et al,  
28                   September/October 1985, J. Vac. Sci. Technol. B3(5)  
29                   pp. 1352-1356.

30                   In the article COMPARISON OF PROPERTIES OF  
31                   DIELECTRIC FILMS DEPOSITED BY VARIOUS METHODS by W.A.  
32                   Pliskin, J. Vac. Sci. Technol. Vol. 14 No. 5,  
33                   Sept./Oct. 1977, pp. 1065-1081, the SiOH and H<sub>2</sub>O  
34                   content in various dielectric thin films is  
35                   described. In the article EVALUATIONS OF PLASMA  
36                   SILICON-OXIDE FILM (P-SiO) BY INFRARED ABSORPTION by  
37                   A. Takamatsu et al, J. Electro. Chem. Soc.:  
38                   Solid-State Science & Technology, Feb. 1986, pp.

443-445, the relationship between the presence of SiOH and failure of semiconductor devices are described.

It is clear that the known process for producing SOG produces SiOH, organic volatiles, and H<sub>2</sub>O including solvents, alcohols, large organometallic molecules and large organic molecules, which is associated with corrosion of metallization lines in contact with SOG, outgassing during metallization resulting in via-poisoning, poor adhesion due to outgassing and other H<sub>2</sub>O, organic volatiles, and SiOH effects, cracking, peeling and flaking of films deposited over SOG due to outgassing related pressure buildup, low breakdown voltage of dielectric combinations with SOG, lossy dielectric combinations with SOG, low density dielectrics due to the presence of H<sub>2</sub>O and SiOH in SOG, reduced meantime between failure in accelerated life test stressing due to the presence of H<sub>2</sub>O, organic volatiles, and SiOH, the requirement for SOG to be subjected to an etch back process, and the result that SOG cannot be used as the constituent of a required high quality dielectric.

After SOG was deposited in order to planarize the surface of a semiconductor, an etch back technique was required to be used in multilevel planarization to remove all of the SOG over the lines of a first level of metallization so as to leave only a minimum amount of SOG in the recesses. This resulted in poor process flexibility, poor process compatibility, the requirement to use expensive etch back equipment, and the necessity of tight specifications for depositions and etch back.

Contact with water was prohibited. Contact with moist air was required to be minimized by using in-situ curing and/or long outgassing cycles after air contact. This has been found to be not really adequate to rid the layer of SiOH, organic volatiles, and H<sub>2</sub>O since some remains even after very

01  
02 long outgassing cycles.

03 The remanent SiOH, organic volatiles, and  
04 H<sub>2</sub>O produced via poisoning. This limited the  
05 technology to large metal via spacings, and thus the  
06 use of SOG adjacent vias was not really practical for  
07 small geometry. Very long back sputter and outgassing  
08 steps were needed to outgas the absorbed water.

09 Indeed, for applications where device  
10 reliability is particularly important, such as for  
11 military applications, the use of SOG technology for  
12 semiconductor integrated circuit applications has been  
13 prohibited.

14 In order to avoid contact of SOG and metal  
15 at places other than the vias for multilevel  
16 metallization, the SOG layer was required to be put  
17 into a sandwich between two dielectric layers to form  
18 a completed dielectric combination of a desired  
19 thickness.

20 The quantity of SOG used was required to  
21 be minimized, and the aspect ratios was adjusted to  
22 obtain everywhere a good combination of dielectric and  
23 SOG.

24 SOG was normally cured thermally in  
25 nitrogen, argon, oxygen, water or forming gas at  
26 temperatures of between 300°C and 450°C for durations  
27 between 30 minutes and 2 hours. Wafer storage,  
28 loading and unloading for process was required to be  
29 done in a dry ambient environment.

30 In the article of Schiltz and Butherus,  
31 attempts were described to cure organic SOG by means  
32 of an oxygen plasma in a barrel reactor.  
33 Unfortunately, as may be seen in the infrared  
34 absorption spectrum in Figure 3 of Butherus, and as  
35 described on page 1354, the five last lines of the  
36 left-hand column, and as shown in Figure 6 of Schiltz,  
37 significant amounts of SiOH and H<sub>2</sub>O are obtained using

that process as a result of the oxidation of the methyl - CH<sub>3</sub> bonds by the active oxygen atoms/molecules. In addition, densification of the SOG occurs due to the production of volatile carbon oxide compounds, which were to be evaporated. However water was also formed as a byproduct, which was found to be retained in the SOG.

In one embodiment of the present invention, an SOG film is produced which is substantially SiOH, organic volatiles and H<sub>2</sub>O free after the treatment. The film has been found to be very stable in moist air and/or water after the treatment. Thus subsequent processing is simplified.

Because of the stability and no apparent formation of SiOH, organic volatiles and H<sub>2</sub>O once the films have been plasma cured, a dry photoresist strip in O<sub>2</sub> plasma is feasible. Via poisoning by SiOH, organic volatiles and H<sub>2</sub>O is eliminated where the SOG formed in accordance with the present invention contacts vias.

SOG films formed by the process of this invention can be stored in moist air for reasonably long periods of time without any appreciable effect on the film after treatment. This is in contrast with tight control required for SOG formed in accordance with the prior art.

It has been found that SOG cured in a plasma which causes an electric field in the SOG film, which can be caused by a DC self-bias in the RF discharge which develops near the surface of the wafer to be treated, will contain substantially no SiOH, organic volatiles and H<sub>2</sub>O, and indeed becomes cured throughout the SOG layer. Further, SOG layers exposed to H<sub>2</sub>O prior to curing in this manner, and thus which have absorbed some H<sub>2</sub>O, have been found to be substantially devoid of H<sub>2</sub>O following a subsequent cure using the process of the present invention. The electrical

effects which cause an electric field within the SOG are of prime importance in the SOG curing and passivation treatment.

It has been found that the barrel plasma reactor used in the prior art does not cause the sufficient required electric field within the SOG being treated. In contrast, a parallel plate reactor does cause the required field to be produced (assuming that the plasma is most positive and the substrate carrying the SOG is in electrical contact with the electrode, as is usual in plasma treatment).

Indeed, the electric field can be enhanced by applying an external AC or DC polarization field to the SOG (including the substrate) to increase the internal electric field thereof.

It has been found that the nature of the gas used is not essential to the invention, and many gases could be used with good results. While an oxygen plasma gas could be used, it is not the preferred gas, for reasons to be described with reference to the given examples.

Large satisfactory SOG thicknesses have been obtained without cracking or adhesion loss, permitting the cured SOG to be used as a dielectric layer itself (i.e. in contact with a semiconductor surface and/or an overlying metal layer), and not solely as a planarizing medium. The dielectric properties of the SOG treated in accordance with the present invention are better than SOG layers described in the prior art, because of water, organic volatiles and SiOH reduction. In addition corrosion of metal lines and other films in contact with the SOG formed in accordance with the present invention because of the water, organic volatiles and SiOH is substantially reduced or eliminated.

Via poisoning is reduced because of water, organic volatiles and SiOH reduction, and the adhesion

01  
02 of films over SOG is improved due to improved  
03 outgassing behaviour due to the water, organic  
04 volatiles and SiOH reduction or elimination. Film  
05 cracking over SOG produced in accordance with the  
06 present invention is minimized or eliminated because  
07 of improved outgassing behaviour due to the water,  
08 organic volatiles and SiOH reduction. Device  
09 reliability is also improved for the same reason.

10 The plasma treatment described herein is  
11 effective for various types of SOG, such as siloxanes,  
12 silicates, doped silicates and other spin-on  
13 materials.

14 A particular embodiment of the present invention employs  
15 a method for producing insulating layers over a  
16 substrate comprising spinning a film of spin-on glass  
17 (SOG) over a silicon wafer, precuring the film of SOG  
18 at an elevated temperature sufficient to remove the  
19 bulk of the solvent of the SOG, and curing the film of  
20 SOG in a plasma in a reactor of a type exhibiting a  
21 self-biased RF discharge adjacent the SOG for a period  
22 of time sufficient to exclude the bulk of SiOH,  
23 organic volatiles and H<sub>2</sub>O from the layer.

24 The  
25 reactor should be of the type which creates an  
26 electric field in the SOG during operation thereof.

27 A reactor which has been found to produce  
28 the above effects is a parallel plate plasma reactor,  
29 such as type AM-3300, manufactured by Applied  
30 Materials Inc.

31 In another embodiment of the invention a  
32 method for producing insulating layers over a  
33 substrate comprises spinning a film of spin-on-glass  
34 SOG over the substrate, precuring the film of SOG at  
35 an elevated temperature sufficient to remove the bulk  
36 of solvent, repeating the steps of spinning and  
37 precuring to form an SOG film having a predetermined  
38 total film thickness and curing the layer of SOG in a

01  
02 plasma in a plasma reactor of a type which creates an  
03 electric field in the SOG during operation thereof for  
04 a period of time sufficient to exclude the bulk of  
05 SiOH, organic volatiles and H<sub>2</sub>O from the layer.

06 Still another embodiment of the invention employs a  
07 method of producing an integrated circuit, which includes the  
08 steps of spinning a film of spin-on-glass (SOG) over a  
09 surface of a wafer to be planarized, precuring the  
10 film of SOG at an elevated temperature sufficient to  
11 remove the bulk of solvent, curing the film of SOG in  
12 a plasma in a plasma reactor of a type which creates  
13 an electric field in the SOG during operation thereof  
14 for a period of time sufficient to exclude the bulk of  
15 SiOH, organic volatiles and H<sub>2</sub>O from the layer,  
16 applying a layer of and defining photoresist on the  
17 surface of the SOG, etching or otherwise treating the  
18 integrated circuit through the defined photoresist,  
19 dry stripping the photoresist in an O<sub>2</sub> plasma, and  
20 applying a layer of metal conductor to the surface of  
21 the SOG over which the photoresist was stripped.

22 In yet another embodiment of the invention a  
23 method of producing an integrated circuit, includes the  
24 steps of spinning a film of spin-on-glass (SOG)  
25 directly over a surface of conductive material to be  
26 insulated, precuring the film of SOG at an elevated  
27 temperature sufficient to exclude the bulk of solvent,  
28 curing the film of SOG in a plasma in a plasma reactor  
29 of a type which creates an electric field in the SOG  
30 during operation thereof for a period of time  
31 sufficient to exclude the bulk of SiOH, organic  
32 volatiles and H<sub>2</sub>O from the layer and applying a  
33 conductive layer directly to the surface of the cured  
34 SOG layer. The conductive layer applied can be a  
35 metal conductor, and the further process steps can be  
36 utilized which are applying photoresist to the surface  
37 of the metal conductor, defining the photoresist by  
38 exposing it to light through a mask, washing away the



photoresist over undesired regions, etching exposed metal conductor, removing the remaining photoresist, cleaning the surface of the circuit, and applying an insulating layer overtop of the circuit in direct contact with the SOG layer.

In a still further embodiment of the invention a method of producing an integrated circuit includes the steps of spinning a film of spin-on-glass (SOG) directly over a surface of lower conductor material to be insulated, precuring the film of SOG at an elevated temperature sufficient to remove the bulk of the solvent, curing the film of SOG at between 200°C and 400°C in a plasma in a plasma reactor of a type which creates an electric field in the SOG during operation thereof for a period of time sufficient to exclude the bulk of SiOH, organic volatiles and H<sub>2</sub>O from the layer, applying a layer of photoresist to the surface of the cured SOG layer, defining the photoresist by exposing its surface to light through a mask, washing away the photoresist over regions for locating conductors, depositing a layer of upper conductor material over the photoresist and exposed SOG layer, removing the remaining photoresist and overlying metal layer, whereupon the conductors are formed, whereby the cured SOG layer forms a dielectric between lower conductor material and the upper conductor material. Then the further step can be undertaken of cleaning the surface, and depositing an insulating layer adherent to and over the exposed SOG surface and the conductors.

In yet a further embodiment of the invention a semiconductor integrated circuit has a layer of spin-on glass thereover which is substantially devoid of SiOH, organic volatiles and H<sub>2</sub>O and a metal conductive layer for the circuit in direct contact with the SOG layer. In further embodiments the layer of spin-on glass is a passivation film, a

planarization film, or a buffer film.

Yet a further embodiment of the invention is a liquid crystal, electrochromic or electroluminescent display having a front surface protectively covered by a layer of spin-on glass which is substantially devoid of SiOH, organic volatiles and H<sub>2</sub>O. The cured SOG layer protects the display from contamination by dissolution of alkali metal.

In yet a further embodiment, the plasma cured SOG devoid of SiOH, organic volatiles and H<sub>2</sub>O is an antireflective coating on a transparent medium. Another embodiment of the invention is a corrosion or chemical protective coating for an object comprised of the plasma cured spin-on-glass layer devoid of SiOH, organic volatiles and H<sub>2</sub>O.

Example 1

P-5 phosphorus doped silicate SOG purchased from Allied Chemical Corp. was coated using multiple coats to obtain a total thickness of about 500 nanometers on silicon semiconductor wafers. The SOG film was precured at 125°C for 60 seconds in moist air at 40% relative humidity, and then at 200°C for 60 seconds in moist air at 40° relative humidity on a hotplate, to remove the bulk of the solvent containing the SOG from the films, between each coat.

After the testing of the final coat, and its proper precure the wafers were cured at 400°C in an oxygen plasma in the AM-3300 parallel plate plasma reactor for 60 minutes at 0.25 Torr, operated at 650 watts and 115 kHz.

The parallel plate plasma reactor generated an electric field adjacent to and within the SOG. After treatment the wafers were placed in contact with moist ambient air, and infrared spectra were recorded.

It was determined that the water content as well as the organics and SiOH content was

substantially reduced, and was substantially smaller than a control set of nitrogen thermally treated films at 400°C to 450°C and not subjected to plasma treatment.

In the case of this oxygen plasma treatment, in place of SiOH bonds, SiH bonds were detected. (This SiH bond formation is not seen in case of non-oxidating plasma treatments).

It was also found that the treatment resulted in a thickness shrink of the films by about 15% (as was reported by Butherus and Schiltz) but in contrast to Butherus and Schiltz, the starting spin-on-glass, P-5, was of inorganic type and oxydation of the methyl bonds Si-CH<sub>3</sub> could not explain the shrink.

It was concluded that the plasma treatment in accordance with the present invention was very effective for the tight bonding, the removal of SiOH, organic volatiles and H<sub>2</sub>O, in contrast to the process described by Butherus and Schiltz, which shows substantial remanence of SiOH and H<sub>2</sub>O.

The treated films were put into contact with deionized water for a period of one hour after plasma treatment. The oxygen plasma treated SOG yielded SOG films which were much more stable than the control nitrogen thermally cured films, which process could not passivate the SOG films against water. However it was found that in the oxygen plasma treated film some of the SiH bonds were consumed to yield some SiOH and H<sub>2</sub>O. Therefore the oxygen plasma treatment, which provided films containing little or no SiOH and H<sub>2</sub>O was observed not to provide a stable passivation against water, and thus is not a preferred plasma gas.

#### Example 2

Silicon wafers were coated with 600 to 675 nanometers thickness of 106 methyl siloxane SOG (organic SOG) purchased from Allied Chemical Corp.

01

- 11 -

02

03

04

05

06

The wafers were precured at 125°C for 60 seconds in moist air and 40% relative humidity and then at 200°C for 60 seconds in moist air at 40% relative humidity on a hotplate, in order to remove the bulk of solvents carrying the SOG.

07

08

09

10

11

12

The wafers were cured at 400°C in a nitrogen plasma in a parallel plate reactor, which caused a self-biasing effect by producing a field adjacent the SOG in the RF discharge and thus an electric field within the SOG, for 60 minutes at 0.25 Torr operating at 650 watts and 115 kHz.

13

14

15

16

17

It was found that the water content in the SOG was nil. Carbon in the form of Si-CH<sub>3</sub> was detected. It was also determined that the nitrogen plasma treated films were just slightly denser than thermally cured control wafers.

18

19

20

The films on the wafers were placed into contact with boiling deionized water for 1 hour. Another infrared spectrum was taken.

21

22

23

24

25

26

27

28

Absolutely no water was detected. Absolutely no SiOH was detected. Undesirable SiH bonds were not produced, although they were produced in the oxygen plasma treatment. The film appeared to be literally unaffected by the 1 hour contact with boiling deionized water (which is nearly the effective equivalent of 5 days contact at 40% relative humidity at 21°C).

29

30

The plasma cure in a nitrogen plasma appeared to be virtually ideal.

31

### Example 3

32

33

34

35

36

Very thick (>1.2 micron in thickness) 106 methyl siloxane SOG obtained from Allied Chemical Corp. was coated using multiple coats as a film on silicon wafers. Such thickness is more than sufficient for intermetal dielectric.

37

38

The films were precured at 125°C for 60 seconds in moist air at 40% relative humidity and then

01  
02 at 200°C for 60 seconds in moist air at 40% relative  
03 humidity, on a hotplate. The precured film on the  
04 substrate was put into contact with boiling deionized  
05 water for 60 minutes to increase its content of water.

06 The film was then cured in a nitrogen  
07 plasma in a parallel plate plasma reactor as described  
08 in the previous examples, but for only 30 minutes at  
09 400°C, operating at 650 watts and 115 kHz.

10 It was found that water absorbed by  
11 contact with deionized water after the precure step  
12 and prior to the plasma cure step was reversed during  
13 the plasma cure. The water did not appear after cure.

14 The nitrogen plasma cure passivated the  
15 SOG film and following the plasma cure and resulting  
16 passivation, almost no additional water absorption  
17 occurred after subsequent contact with moist air  
18 and/or boiling water. This is in contrast with the  
19 reported results on SOG thermal cures.

20 Photoresist dry strip was shown to have  
21 almost no effect on SOG film. This is contrast with  
22 reported results on thermal cures of this organic SOG.

23 It was determined that very thick SOG  
24 films can be coated without cracking and peeling  
25 during curing and contrast with reported results on  
26 SOG thermal cures. The N<sub>2</sub> cure resulted in no water  
27 content in the SOG film.

28 Essential steps of the last example thus  
29 can be used in a non-etch back, highly flexible, high  
30 quality SOG technology, in which the SOG could be used  
31 as a dielectric by itself, in contact with a  
32 semiconductor surface, in contact with vias or other  
33 metal conductors, as an insulator between two metal  
34 layers, without poisoning effect, and with good  
35 adherence to its underlying and overlying layers. Of  
36 course it can also be used in combination with another  
37 dielectric. The etch back and sandwich techniques  
38 required in order to use SOG in accordance with the

prior art need not be used to produce products when the steps of the present invention are used. Accordingly the present invention includes structures which contain an SOG layer which is devoid of SiOH, organic volatiles and H<sub>2</sub>O, used as a dielectric, insulator, etc.

It should be noted that the SOG film may be applied in many coats to improve planarization. In this case, a first coat is spun on the substrate, which should be precured; a second coat is spun on overtop of the underlying precured coat, which is precured; a third coat is spun on overtop of the underlying precured coat, which is precured; etc, after which the entire precured multicoated layer is cured in the plasma as described earlier.

The types of film that can be plasma cured are not restricted to silicon oxide types of SOGs. For example, types of spin-on coatings based on spin-on boron oxide, phosphorus oxide, arsenic oxide, aluminum oxide, zinc oxide, gold oxide, platinum oxide, antimony oxide, indium oxide, tantalum oxide, cesium oxide, iron oxide, or any combination thereof can be cured using the present invention.

In addition, spin-on coating types of materials formed of nitrides and oxinitrides of boron, phosphorus, arsenic, aluminum, zinc, gold, platinum, antimony, indium, tantalum, cesium and iron could be similarly cured and used.

The spin-on-glass can be either silicates undoped or doped with any of known, phosphorus, arsenic, aluminum, zinc, gold, platinum, antimony, indium, tantalum, cesium and iron or methyl siloxanes undoped or doped with the above elements, ethyl siloxanes undoped or doped with the above elements, butyl siloxanes undoped or doped with the above elements, phenyl siloxanes undoped or doped with the above elements, or combinations of any of the

above-noted siloxanes.

Films plasma cured in accordance with this invention need not be restricted to interlayer dielectrics. Some applications and structures thereof are as a diffusion source for doping of substrates, as a passivation film, as a planarization film, as a buffer film, as a preventive film for dissolution of alkali metals (e.g. for displays such as liquid crystal, electrochromic or electroluminescent compounds), as an antireflective coating and other substances used for selective photon absorption, increased chemical resistance, friction reduction, corrosion protection, increased adhesion, etc.

For various applications, optimization of the process can include varying the distance between the plasma glow and the film to be treated, the application of an external polarization field (which can be either DC or AC) to the substrate or substrate holder to enhance the process by increasing the internal electric fields in the SOG film, variation of pressure, power, frequency, gas, gas mixture, mass flow, film temperature and time of treatment, etc.

The films produced by the process described herein can be used on or as part of integrated circuits, emission diode devices, liquid crystal, electrochromic and electroluminescent displays, photodetectors, solar batteries, etc. It can be applied to optical filters, antireflectors, as a passivation film on objects to be protected, as a corrosion protection layer, as an adhesion promoter, as a friction reducer, in mechanical field applications, etc.

CLAIMS

1. A method of producing insulating layers over a semiconductor substrate comprising:
  - (a) spinning a film of spin-on-glass (SOG) over a semiconductor substrate,
  - (b) precuring the film of SOG at an elevated temperature sufficient to remove the bulk of solvent,
  - (c) curing the film of SOG in a plasma in a plasma reactor of a type exhibiting a self-biased RF discharge adjacent the SOG for a period of time sufficient to exclude the bulk of SiOH, organic volatiles and H<sub>2</sub>O from the layer.
2. A method as defined in claim 1 in which the reactor is a parallel plate plasma reactor.
3. A method as defined in claim 1 in which the plasma is a non-oxydising plasma.
4. A method as defined in claim 1 in which the plasma is a nitrogen plasma.
5. A method as defined in claim 4 including using an RF field in the plasma at about 115 kHz, a power density of about .2 watt/cm<sup>2</sup>, a pressure of about .25 Torr, a mass flow rate of 750 SCCM, a current density of about .4 ma/cm<sup>2</sup> through the cathode of the reactor, and a curing period of between about 30 to 60 minutes whereby the substrate reaches a temperature of about 400°C.
6. A method as defined in claim 2 including the step of applying an external



polarization field to the substrate to increase the internal electrical field in the SOG.

7. A method as defined in claim 2 or 6 in which the SOG is of a type selected from the group consisting of silicon dioxide, boron oxide, phosphorus oxide, arsenic oxide, aluminum oxide, zinc oxide, gold oxide, platinum oxide, antimony oxide, indium oxide, tantalum oxide, cesium oxide and iron oxide, or any combination thereof.

8. A method as defined in claim 2 or 6 in which the SOG is of a type selected from the group consisting of the oxides, nitrides or oxynitrides of boron, phosphorus, arsenic, aluminum, zinc, gold, platinum, antimony, indium, tantalum, cesium, and iron or any combination thereof.

9. A method as defined in claim 2 or 6 in which the SOG is a silicon oxide type obtained from one of an organic SOG solution and an inorganic (siloxane) SOG solution.

10. A method for producing insulating layers over a substrate comprising:

(a) spinning a film of spin-on-glass SOG over the substrate,

(b) precuring the film of SOG at an elevated temperature sufficient to remove the bulk of solvent,

(c) repeating steps (a) and (b) to form an SOG film having a predetermined total film thickness,

(d) curing the layer of SOG in a plasma in a plasma reactor of a type which creates an electric field in the SOG during operation thereof for a period of time sufficient to exclude the bulk of  $\text{SiOH}$ , organic volatiles and  $\text{H}_2\text{O}$  from the layer.

11. A method as defined in claim 10 including the step of applying an external polarization field to the SOG and the substrate to increase internal electrical fields thereof.

12. A method as defined in claim 10 in which the reactor is a parallel plate plasma reactor.

13. A method as defined in claim 12 including the step of allowing contact of the surface of the SOG film with moisture or water prior to curing.

14. A method as defined in claims 2, 3 or 10 in which the SOG is selected from the group consisting of a doped or undoped silicate, and a doped or undoped methyl, ethyl, butyl and phenyl siloxane, the dopant being selected from the group consisting of boron, phosphorus, arsenic, aluminum, zinc, gold, platinum, antimony, indium, tantalum, cesium and iron.

15. A method as defined in claim 2, 5 or 10 in which the SOG is a silicate or siloxane material doped with phosphorus.

16. In a method of producing an integrated circuit, the steps of

(a) spinning a film of spin-on-glass (SOG) over a surface of a wafer to be planarized,

(b) precuring the film of SOG at an elevated temperature sufficient to remove the bulk of solvent,

(c) curing the film of SOG at between 200°C and 400°C in a plasma in a plasma reactor of a type which creates an electric field in the SOG during operation thereof for a period of time sufficient to exclude the bulk of SiOH, organic volatiles and H<sub>2</sub>O

from the layer.

(d) applying a conductive layer to the surface of the integrated circuit such that it makes direct contact with the cured layer of SOG.

17. A method as defined in claim 14 in which the reactor is a parallel plate plasma reactor.

18. A method as defined in claim 17 in which the SOG is of a type selected from the group consisting of silicon dioxide, boron oxide, phosphorus oxide, arsenic oxide, aluminum oxide, zinc oxide, gold oxide, platinum oxide, antimony oxide, indium oxide, tantalum oxide, cesium oxide and iron oxide, or any combination thereof.

19. A method as defined in claim 17 in which the SOG is of a type selected from the group consisting of the oxides, nitrides or oxynitrides of boron, phosphorus, arsenic, aluminum, zinc, gold, platinum, antimony, indium, tantalum, cesium, and iron, or any combination thereof.

20. In a method of producing an integrated circuit, the steps of

(a) spinning a film of spin-on-glass (SOG) over a surface of a wafer to be planarized,

(b) precuring the film of SOG at an elevated temperature sufficient to remove the bulk of solvent,

(c) curing the film of SOG in a plasma in a plasma reactor of a type which creates an electric field in the SOG during operation thereof for a period of time sufficient to exclude the bulk of  $\text{SiOH}$ , organic volatiles and  $\text{H}_2\text{O}$  from the layer.

(d) applying a layer of and defining photoresist on the surface of the SOG,

- (e) etching or otherwise treating the integrated circuit through the defined photoresist,
- (f) dry stripping the photoresist in an O<sub>2</sub> plasma, and
- (g) applying a layer of metal conductor to the surface of the SOG over which the photoresist was stripped.

21. In a method as defined in claim 20, the additional step, following the curing step and prior to applying a layer of photoresist, of depositing a layer of dielectric over the cured film of SOG.

22. In a method of producing an integrated circuit, the steps of

- (a) spinning a film of spin-on-glass (SOG) directly over a surface of conductive material to be insulated,
- (b) precuring the film of SOG at an elevated temperature sufficient to exclude the bulk of solvent,
- (c) curing the film of SOG in a plasma in a plasma reactor of a type which creates an electric field in the SOG during operation thereof for a period of time sufficient to exclude the bulk of SiOH, organic volatiles and H<sub>2</sub>O from the layer,
- (d) applying a conductive layer directly to the surface of the cured SOG layer.

23. A method as defined in claim 22 in which the reactor is a parallel plate plasma reactor.

24. A method as defined in claim 23 in which the SOG is a silicon oxide type.

25. A method as defined in claim 22, 23,

or 24, in which the conductive layer applied in step (d) is a metal conductor including the further steps of applying photoresist to the surface of the metal conductor, defining the photoresist by exposing it to light through a mask, washing away the photoresist over undesired regions, etching exposed metal conductor, removing the remaining photoresist, cleaning the surface of the circuit, and applying an insulating layer overtop of the circuit in direct contact with the SOG layer.

26. In a method of producing an integrated circuit, the steps of

(a) spinning a film of spin-on-glass (SOG) directly over a surface of lower conductor material to be insulated,

(b) precuring the film of SOG at an elevated temperature sufficient to remove the bulk of the solvent,

(c) curing the film of SOG at between 200°C and 400°C in a plasma in a plasma reactor of a type which creates an electric field in the SOG during operation thereof for a period of time sufficient to exclude the bulk of SiOH, organic volatiles and H<sub>2</sub>O from the layer.

(d) applying a layer of photoresist to the surface of the cured SOG layer,

(e) defining the photoresist by exposing its surface to light through a mask, washing away the photoresist over regions for locating conductors,

(f) depositing a layer of upper conductor material over the photoresist and exposed SOG layer,

(g) removing the remaining photoresist and overlying metal layer, whereupon said conductors are formed,

whereby the cured SOG layer forms a dielectric between the lower conductor material and

the upper conductor material.

27. A method as defined in claim 26, including the further step of cleaning said surface, then depositing an insulating layer adherent to and over the exposed SOG surface and the conductors.

28. A semiconductor integrated circuit having a layer of plasma cured spin-on-glass thereon which is substantially devoid of SiOH, organic volatiles and H<sub>2</sub>O and a metal conductive layers for the circuit in direct contact with the SOG layer.

29. An integrated circuit as defined in claim 28 formed in part by the method of one of claims 22 - 27.

30. An integrated circuit having a layer of plasma cured spin-on-glass which is substantially devoid of SiOH, organic volatiles and H<sub>2</sub>O as a passivation film.

31. An integrated circuit having a layer of plasma cured spin-on-glass which is substantially devoid of SiOH, organic volatiles and H<sub>2</sub>O as a planarization film.

32. An integrated circuit having a layer of plasma cured spin-on-glass which is substantially devoid of SiOH, organic volatiles and H<sub>2</sub>O as a buffer film.

33. A liquid crystal, electrochromic or electroluminescent crystal display having a front surface protectively covered by a layer of plasma cured spin-on-glass which is substantially devoid of SiOH, organic volatiles and H<sub>2</sub>O.

34. An antireflective coating on a transparent medium having a front surface protectively covered by a layer of plasma cured spin-on-glass which is substantially devoid of SiOH, organic volatiles and H<sub>2</sub>O.

35. A corrosion or chemical protective coating for an object having a front surface protectively covered by a layer of plasma cured spin-on-glass which is substantially devoid of SiOH, organic volatiles and H<sub>2</sub>O.

36. An integrated circuit having a layer of spin-on-glass has been formed using the process of one of claims 1, 7, 8, 9, 22 and 23.

37. A liquid crystal, electrochromic or electroluminescent display having a front surface protectively covered by a layer of plasma cured spin-on-glass which has been formed using the process of one of claims 10-13.

38. A coating on an object formed of spin-on-glass which has been formed using the process of one of claims 10-13.

39. A method as defined in claim 17 in which the gas used in the plasma reactor is a non-oxidizing gas.

40. A method as defined in claim 17 in which the gas used in the plasma reactor is nitrogen.

41. An integrated circuit as defined in claim 28 in which the SOG layer is at least 0.5 microns in thickness.

42. A method of producing a layer on a substrate substantially as described herein with reference to any one of examples 1 to 3.

